arXiv:hep-ex/0012028v1 11 Dec 2000

MEASUREMENT OF sin($2\phi_1$) AT BELLE

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With 6.2 fb^{-1} of data collected on the $\Upsilon(4S)$, Belle reports its first measurement of $\sin 2\phi_1 = 0.45^{+0.43}_{-0.44}(\mathrm{stat})^{+0.07}_{-0.09}(\mathrm{sys})$. The result was obtained by fitting the proper time distribution of flavor tagged and fully reconstructed neutral B mesons decays to five different charmonia plus a K_s or K_L channels. In this paper the analysis and results will be described briefly.

1. Introduction

In the Standard Model, the violation of the CP symmetry by the weak interaction is possible via the complex phase in the CKM mass mixing matrix. This phase can be extracted by observing processes that involve flavor transitions spanning the three quark generations. In this analysis we consider decays of the neutral B meson to final states which are CP eigenstates. The interference between the weak phase in direct decays and decays that proceed via mixing leads to an asymmetry in the time-dependent decay rate which is exploited here to measure the value of $\sin 2\phi_1$,($\sin 2\beta$). The particular decay modes considered were selected because they have relatively large branching fractions, clear experimental signatures and are essentially free from theoretical uncertainties. Five neutral B decay channels were used: $B \to J/\psi K_S, \psi(2S)K_s$, $\chi_{c1}K_s$, $J/\psi K_L$ and $J/\psi\pi^0$. The first three channels have odd CP while the last two have even CP.

2. Analysis Procedure

Our analysis includes all of the available data collected by the Belle experiment[1] up through the end of the Summer 2000. The data sample consists of 6.2 fb^{-1} taken at the $\Upsilon(4S)$. At Belle, the center of mass of $B\bar{B}$ pair system is boosted by the asymmetric configuration of the e^+e^- beams. The boost ($\gamma\beta = 0.425$), the long-lifetime of the B meson and the excellent resolution of the silicon-vertex detector makes possible measurements of time-dependent decay rates from the displacement of the reconstructed B vertices in the boost direction. To deduce the flavor of the B_{CP} meson, its decays to a CP-eigenstate is flavor non-specific, we tag the flavor of

the B_{tag}, the other B meson.[a] The relationship between the time-dependent decay rate, in terms of the proper-time $\Delta t = t_{CP} - t_{tag}$, and the CP violating parameter is given by,

$$\frac{dN}{d\Delta t}(B \to f_{CP}) \propto e^{-\Gamma|\Delta t|}\{1 - (1-2\omega)\eta_{CP}\sin 2\phi_1 \sin(\Delta m \Delta t)\}, \tag{1}$$

here Δm determines the frequency of $B^0\bar{B}^0$ mixing, η_{CP} is either $+1(-1)$ for even(odd) CP final states and $\sin 2\phi_1$ is the CP-violating term. The $(1-2\omega)$ term, known as the dilution factor, accounts for the possibility of mis-assigning the flavor to the B_{tag} (wrong-tag).

The analysis procedure used to extract the value of $\sin 2\phi_1$ includes four main components: (1) reconstruct, exclusively, the decay of the B_{CP} meson and identify candidate events, (2) determine the flavor of B_{CP}, at the decay time of B_{tag} by tagging its flavor, (3) determine the proper-time of the decay by measuring the difference between the z decay vertices of the two B mesons and compute the proper-time from the $\Delta t = \Delta z/\gamma\beta$ relation and (4) form the proper-time distribution from the sample of tagged and fully reconstructed events and extract the value of $\sin 2\phi_1$ from an unbinned maximum likelihood fit.

2.1. *Reconstruction of the* B_{CP} *decay* [2,3]

Event shape variables were used to reject continuum background and particle identification requirements were imposed on tracks used to reconstruct the decay products of the B_{CP}. To form J/ψ and $\psi(2S)$ candidates we used dilepton channels $(\mu^+\mu^-, e^+e^-)$, correcting for final-state radiation in the electron channel. For $\psi(2S)$ candidates we also used the $J/\psi\pi^+\pi^-$ mode. For χ_{c1} candidates we used only the $J/\psi\gamma$ decay channel. K_s candidates were selected from among $\pi^+\pi^-$ and $\pi^0\pi^0$ combinations. The neutral mode was used exclusively in the reconstruction of $B \to J/\psi K_s$. The signals for CP eigenstates were identified kinematically via the beam-constrained mass and ΔE (variables in which the beam-energy is substituted for the measured energy) distributions, see Fig. 1. The total number of B candidates found for each mode are listed in Table 1.

2.2. *Flavor Tagging* [3]

To determine the flavor of the B_{CP} candidates, we examined the remaining tracks in the event to identify the flavor of B_{tag}. The flavor tagging algorithm employs four methods: (1) high momentum ($p_l^* > 1.1$GeV/c) lepton charge; this tags the b quark flavor via its primary decay to a lepton, (2) sum of the charge for all well identified kaons; this tag relies on the flavor of the s quark from cascade decays, (3) medium momentum lepton ($0.6 < p_l^* < 1.1$ GeV/c); here if the sum of p_l^* and p_{miss}^* is greater than 2.0 GeV/c then the charge of the lepton tags the b quark

[a] Since, the decay of the $\Upsilon(4s)$ creates a pair of $B\bar{B}$ mesons in a coherent quantum state, tagging the flavor of one of the B automatically determines the flavor of the other B at the time when the tagged B decayed.

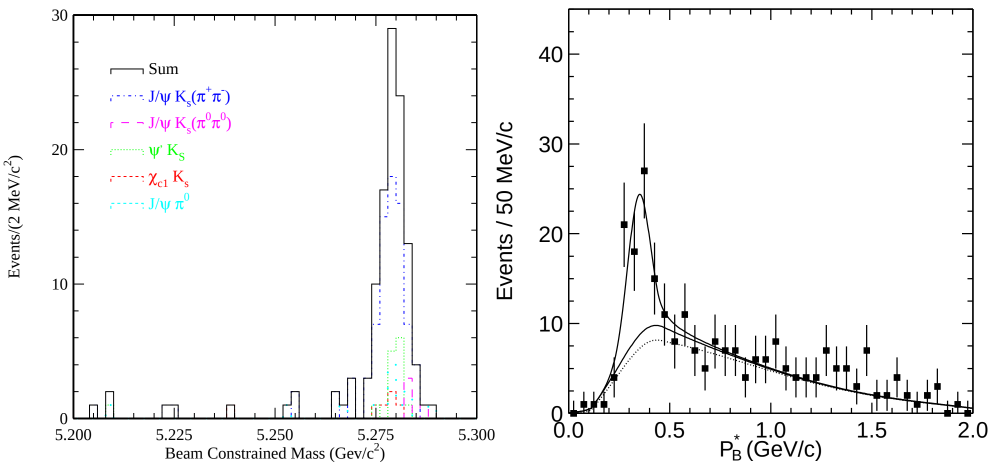

Fig. 1. The plot on the left, shows the beam-constrained mass distribution used to identify the number of reconstructed B_{CP} in all but the $J/\psi K_L$ mode. The plot on the right, shows the p_B^* distribution used to identify the $J/\psi K_L$. The signal region in p_B^* is defined from 0.2 to 0.45 GeV/c. The background distribution in the fit is divided into components describing the contribution from resonant and (non-resonant) $B \to J/\psi K^{*0}(K_L \pi^0)$ and all other B decays.

flavor as in (1). (4) slow pion charge; this method tags the flavor of charged D^* from the decay of the B and thus its flavor. The methods are applied sequentially. The efficiency and wrong tag fractions are determined from Monte Carlo studies and from analysis of a sample of self-tagging exclusively reconstructed $B \to D^{(*)} l \nu$ decays. The effective efficiencies ($\epsilon_{eff} = (1-2\omega)^2$) range from 10.5% to 0.7% and with a total of about 22%. The number of reconstructed B mesons which were flavor-tagged are listed in Table 1.

2.3. *Vertexing and extraction of* $\sin 2\phi_1$ [3]

The value of $\sin 2\phi_1$ is extracted from an unbinned maximum-likelihood fit to the proper-time distribution of tagged and fully reconstructed B_{CP} decays. The proper-

Table 1. Number of B_{CP} candidates reconstructed and tagged

CP	B **Decay Mode**	**Signal**	**Background**	**Tagged**
-1	$J/\psi K_s, K_s \to \pi^+\pi^-$	70	3.4	40
-1	$J/\psi K_s, K_s \to \pi^0\pi^0$	4	0.3	4
-1	$\psi(2s)K_s, \psi(2s) \to l^+l^-$	5	0.2	2
-1	$\psi(2s)K_s, \psi(2s) \to J/\psi\pi^-\pi^+$	8	0.6	3
-1	$\chi_{c1}K_s$	5	0.8	3
$+1$	$J/\psi K_L$	102	48.0	42
$+1$	$J/\psi \pi^0$	10	0.6	4
	Total	204	53.9	98

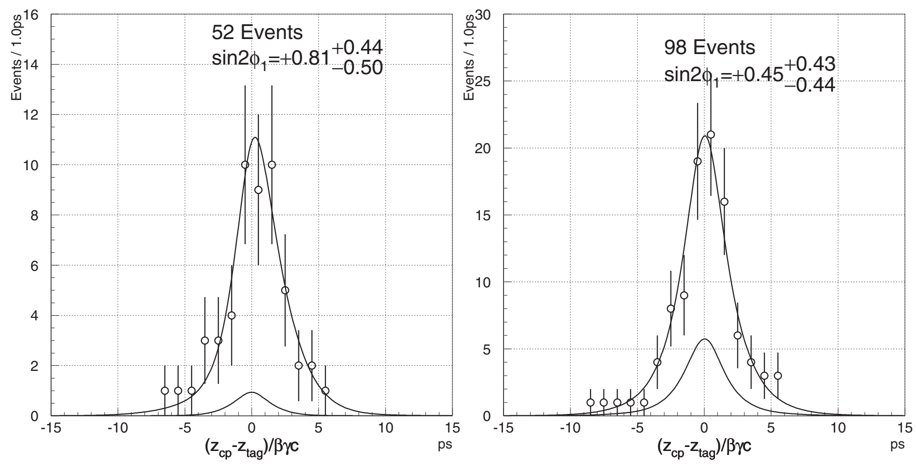

Fig. 2. The fitted proper-time distribution including data from both B^0 and $\bar{B}^0$ candidates ($dN/d\Delta t|_{B^0} + dN/d(-\Delta t)|_{\bar{B}^0}$). The plot on the left includes all modes with odd CP. The plot on the right includes all modes.

time for each candidate event was estimated from $\Delta z/\beta\gamma c$ where Δz is the difference between the decay vertices of the B_{CP} and B_{tag}. The vertex position of the B_{CP} was established by the two tracks assigned to the J/ψ candidate. The vertex position of the B_{tag} was determined from tracks not assigned to B_{CP} by an algorithm that removes tracks which originate in secondary vertices or do not contribute positively to the vertex fit.

To improve the statistical accuracy of our measurement the data from all decay modes including those with odd and even CP were combined in the final likelihood fit. The likelihood function for each event takes into account the finite resolution of the detector, the charm-lifetime and includes terms for background contributions from decays with or without their own CP asymmetry. The CP-asymmetry, $B^0\bar{B}^0$ mixing and dilution due to wrong-tagged events were included in the functional form as illustrated by Equation 1. The maximum-likelihood fits to the data are shown in Fig. 2. Our preliminary result is:

$$\sin 2\phi_1 = 0.45^{+0.43}_{-0.44}(\text{stat})^{+0.07}_{-0.09}(\text{sys}). \tag{2}$$

The systematic error includes effects from uncertainty in the fraction of wrong tags, the Δt resolution function for both background and signal and input values used for B lifetime and mixing parameter. The dominant effect comes from the uncertainty in the wrong tagged fraction. We also checked for biases in the analysis by examining modes where no CP-asymmetry is expected. In particular we ran the entire analysis including the vertexing, tagging and CP-fitting algorithm on reconstructed samples of $B \to J/\psi K^{*0}(K^-\pi^+)$,$B^- \to J/\psi K^-$, $B^- \to D^0\pi^-$ and $B^0 \to D^{*-}l^+\nu$. We observed no CP-asymmetry in these modes as expected.

3. Conclusion

We have obtained a preliminary value for the $\sin 2\phi_1$ by analyzing 6.2 fb^{-1} of data collected at the $\Upsilon(4S)$. Due to the large statistical errors our result does not, at this time, show conclusive evidence for CP violation in the B system. As more data become available we expect to significantly improve the accuracy of our measurement and establish whether or not the Standard Model can account for CP violation in the B system.

4. References

1. The Belle Collaboration, "*The Belle Detector*," to be submitted to Nucl. Inst. Meth.
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3. H. Aihara, "*A Measurement of* CP *Violation in* B^0 *Meson Decays With Belle*," to appear in the Proceeding of the $\mathrm{XXX}^{\mathrm{th}}$ International Conference on High Energy Physics, Osaka Japan, July 2000. e-Print hep-ex/0010008